CLAIMS

We claim:

1. A method of quantum computing, comprising:

providing a qubit, the qubit including a multi-terminal junction wherein two terminals of the multi-terminal junction are coupled to form a superconducting loop, the superconducting loop providing a phase shift;

initializing a quantum state in each of the qubits in the array of qubits;

performing an algorithm with the array of qubits; and

reading out a final quantum state of each of the qubits in the array.

2. The method of Claim 1, wherein providing a qubit comprises providing a multi-terminal junction that includes at least one constriction junction.

3. The method of Claim 1, wherein providing a qubit comprises providing a multi-terminal junction that includes at least one tunnel junction.

4. The method of Claim 3, wherein providing a multi-terminal junction with at least one tunnel junction includes forming an insulating layer separating two of the at least two terminals.

5. The method of Claim 4, wherein providing a multi-terminal junction with at least one tunnel junction includes forming two terminals of the multi-terminal junction with an s-wave superconducting material.

6. The method of Claim 1, wherein providing a qubit includes providing a multi-terminal junction that includes at least one two-dimensional electron gas structure.

7. The method of Claim 6, wherein providing a multi-terminal junction that includes one two-dimensional electron gas includes forming a two-dimensional electron gas by depositing an InAs layer onto an AlSb substrate.

8. The method of Claim 1, wherein providing a qubit includes providing a superconducting loop that includes a first portion of a s-wave superconducting material and a second portion of a s-wave superconducting material and wherein a portion of the phase shift is produced by a d-wave superconducting material coupled to the first portion and the second portion through normal metal interfaces, the portion of the phase shift being determined by the angle between the normal metal interface and crystallographic directions in the d-wave superconducting material.

9. The method of Claim 1, wherein providing a qubit includes providing a superconducting loop that includes a first portion of a s-wave superconducting material and a second portion of a s-wave superconducting material and wherein a portion of the phase shift is produced by a first d-wave superconducting material coupled through a normal metal to the first portion and a second d-wave superconducting material coupled through a second normal metal to the second portion, the portion of the phase shift being determined by the difference in crystallographic directions in a grain boundary interface between the first d-wave superconducting material and the second d-wave superconducting material.

10. The method of Claim 9, wherein providing the superconducting loop includes forming the first d-wave superconducting material and the second d-wave superconducting material on insulating crystals.

11. The method of Claim 9, wherein providing the superconducting loop includes providing the s-wave superconducting material chosen from a group consisting of Aluminum, Niobium, Lead, Mercury, and Tin.

12. The method of Claim 9, wherein providing the superconducting loop includes providing the d-wave superconducting material from $YBa_2Cu_3O_{7-x}$.

13. The method of Claim 10, wherein forming the first d-wave superconducting material and the second d-wave superconducting material on the insulating crystals includes forming a d-wave material on a material chosen from the group consisting of Strontium Titanate, Sapphire, Cerium Oxide, and Magnesium Oxide.

14. The method of Claim 1, wherein forming a qubit includes forming a superconducting loop that includes a ferromagnetic junction, a portion of the phase shift being produced by the ferromagnetic junction.

15. The method of Claim 14, wherein forming the superconducting loop includes forming a first portion and a forming second portion wherein the first portion and the second portion are coupled by the ferromagnetic junction.

16. The method of Claim 15, wherein forming the first portion and forming the second portion each include forming portions from s-wave superconducting material.

17. The method of Claim 16, wherein the s-wave superconducting material is chosen from the group consisting of Aluminum, Niobium, Lead, Mercury, and Tin.

18. The method of Claim 16, wherein the ferromagnetic junction is formed by copper or Nickel sandwiched between the first portion and the second portion.

19. The method of Claim 16, wherein forming the superconducting loop includes implanting a ferromagnetic material into an s-wave superconducting material coupled between the first portion and the second portion.

20. The method of Claim 1, wherein forming the qubit includes forming a superconducting loop from a d-wave superconducting material wherein a portion of the phase shift is formed by grain boundaries in the d-wave superconducting material of the superconducting loop.

21. The method of Claim 1, wherein initializing the quantum state includes applying transport currents to the superconducting loop through terminals of the multi-terminal junctions.

22. The method of Claim 21, wherein applying transport currents includes applying a current asymmetrically through the multi-terminal junction in a first direction to initialize a first state and applying a current asymmetrically through the multi-terminal junction in a second direction to initialize a second state.

23. The method of Claim 1, wherein initializing the quantum state includes reading the qubit and providing a current symmetrically through the multi-terminal junction if the qubit is in a state opposite to a desired state.

24. The method of Claim 1, wherein initializing the quantum state includes applying an external magnetic field to the qubit.

25. The method of Claim 1, wherein reading out the final quantum state includes applying a transport current asymmetrically through the multi-terminal junction and measuring a voltage across the multi-terminal junction.

26. The method of Claim 25, wherein measuring the voltage across the multi-terminal junction comprises using a radio frequency single electron transistor electrometer.

27. The method of Claim 25, wherein applying a transport current includes applying a transport current greater than a critical current of the multi-terminal junction corresponding to a first state and smaller than a critical current of the multi-terminal junction corresponding to a second state.

28. The method of Claim 27, further including determining the quantum state to be the first state if no voltage is measured across the multi-terminal junction and determining the quantum state to be the second state if a voltage is measured across the multi-terminal junction.

29. The method of Claim 1, wherein reading out the final quantum state includes measuring the direction of the magnetic field of the superconducting loop with a magnetic force microscope.

30. The method of Claim 1, wherein reading out the final quantum state includes measuring the magnetic field of the superconducting loop with a SQUID loop.

31. The method of Claim 1, wherein reading out the final quantum state includes measuring the magnetic field of the superconducting loop with a Hall probe.

32. The method of Claim 1, wherein performing an algorithm includes externally applying magnetic fields to the qubit.

33. The method of Claim 1, wherein performing an algorithm includes applying transport currents through the multi-terminal junction.

34. The method of Claim 1, wherein performing an algorithm includes performing a σ_x phase gate operation or a σ_z phase gate operation.

35. The method of Claim 34, wherein performing a σ_x phase gate operation includes passing a pulse of current symmetrically through the multi-terminal junction.

36. The method of Claim 34, wherein performing a σ_z phase gate operation includes passing a pulse of current asymmetrically through the multi-terminal junction.

37. The method of Claim 1, further comprising:
providing a second qubit; and
coupling the second qubit with the qubit with an entanglement junction, wherein performing an algorithm further includes controlling an entanglement between quantum state of the qubit with quantum state of the second qubit.

38. The method of Claim 37, wherein controlling the entanglement includes capacitively coupling a voltage into the entanglement junction in order to remove an entanglement and removing the voltage to provide an entanglement.

39. The method of Claim 1, wherein the multi-terminal junction includes five-terminals and wherein initializing a quantum state includes passing a

transport current directionally and asymmetrically through the five-terminal junction for a sufficient period of time for a quantum state of the superconducting loop coupled to the five-terminal junction to relax into the preferred state.

40. The method of Claim 39, wherein reading out the final state includes applying a current asymmetrically through the five-terminal junction and measuring a voltage across the five-terminal junction, the current being between a first critical current and a second critical current, and absence or presence of the voltage indicating the quantum state of the qubit.

41. The method of Claim 39, wherein performing an algorithm includes performing a first gate operation by passing a pulse of current asymmetrically through the multi-terminal junction or performing a second gate operation by passing a pulse of current symmetrically through the multi-terminal junction.

42. The method of Claim 41, wherein the duration and intensity of transport currents that perform the first phase gate operation and the second phase gate operation are short enough and small enough respectively such that the quantum state of the qubit is not destroyed by the operation.

43. The method of Claim 1, further including providing at least one other qubit

44. The method of Claim 43, wherein providing the at least one other qubit includes forming a second superconducting loop by coupling a second pair of terminals of the multi-terminal junction of the qubit.

45. The method of Claim 43, wherein providing the at least one other qubit includes coupling the qubit to the at least one of the at least one other qubit through multi-terminal junctions.

46. The method of Claim 43, further including coupling the at least one other qubit with the qubit through an entanglement junction.

47. The method of Claim 1, further including tuning the qubit.

48. The method of Claim 47, wherein tuning the qubit includes passing a current symmetrically through the multi-terminal junction.

49. The method of Claim 47, wherein tuning the qubit includes passing a current symmetrically through the multi-terminal junction so that a tunneling frequency for the qubit matches a tunneling frequency of other qubits in an array of qubits.

50. A method of initializing a qubit, comprising:

providing a qubit, the qubit including a superconducting loop coupled to a multi-terminal junction, the superconducting loop providing a phase shift; and

passing current asymmetrically through the multi-terminal junction in a selected direction for a sufficient amount of time to induce a selected quantum state on the superconducting loop of the quantum qubit.

51. The method of Claim 50, wherein providing a qubit comprises providing a multi-terminal junction that includes at least one constriction junction.

52. The method of Claim 50, wherein providing a qubit comprises providing a multi-terminal junction that includes at least one tunnel junction.

53. The method of Claim 50, wherein providing a qubit includes providing a multi-terminal junction that includes at least one two-dimensional electron gas structure.

54. The method of Claim 50, wherein providing a qubit includes providing a superconducting loop that includes a first portion of a s-wave superconducting material and a second portion of a s-wave superconducting material and wherein a portion of the phase shift is produced by a d-wave superconducting material coupled to the first portion and the second portion through normal metal interfaces, the portion of the phase shift being determined by the angle between the normal metal interface and crystallographic directions in the d-wave superconducting material.

55. The method of Claim 50, wherein providing a qubit includes providing a superconducting loop that includes a first portion of a s-wave superconducting material and a second portion of a s-wave superconducting material and wherein a portion of the phase shift is produced by a first d-wave superconducting material coupled through a normal metal to the first portion and a second d-wave superconducting material coupled through a second normal metal to the second portion, the portion of the phase shift being determined by the difference in crystallographic directions in a grain boundary interface between the first d-wave superconducting material and the second d-wave superconducting material.

56. The method of Claim 50, wherein forming a qubit includes forming a superconducting loop that includes a ferromagnetic junction, a portion of the phase shift being produced by the ferromagnetic junction.

57. The method of Claim 50, wherein forming the superconducting loop includes forming a first portion and a forming second portion wherein the first portion and the second portion are coupled by the ferromagnetic junction.

58. The method of Claim 50, wherein forming the qubit includes forming a superconducting loop from a d-wave superconducting material wherein a

portion of the phase shift is formed by grain boundaries in the d-wave superconducting material of the superconducting loop.

59. The method of Claim 50, wherein the multi-terminal junction is a five-terminal junction.

60. The method of Claim 50, wherein if the selected quantum state is a first state then initializing the quantum state includes passing current asymmetrically through the multi-terminal junction in a first direction.

61. The method of Claim 50, wherein if the selected quantum state is a second state then initializing the quantum state includes passing current asymmetrically through the multi-terminal junction in a second direction opposite the first direction.

62. A method of performing a phase gate operation, comprising:

providing a qubit, the qubit including superconducting loop coupled to a multi-terminal junction, the superconducting loop providing a phase shift;

passing current through the multi-terminal junction.

63. The method of Claim 62, wherein providing a qubit comprises providing a multi-terminal junction that includes at least one constriction junction.

64. The method of Claim 62, wherein providing a qubit comprises providing a multi-terminal junction that includes at least one tunnel junction.

65. The method of Claim 62, wherein providing a qubit includes providing a multi-terminal junction that includes at least one two-dimensional electron gas structure.

66. The method of Claim 62, wherein providing a qubit includes providing a superconducting loop that includes a first portion of a s-wave superconducting material and a second portion of a s-wave superconducting material and wherein a portion of the phase shift is produced by a d-wave superconducting material coupled to the first portion and the second portion through normal metal interfaces, the portion of the phase shift being determined by the angle between the normal metal interface and crystallographic directions in the d-wave superconducting material.

67. The method of Claim 62, wherein providing a qubit includes providing a superconducting loop that includes a first portion of a s-wave superconducting material and a second portion of a s-wave superconducting material and wherein a portion of the phase shift is produced by a first d-wave superconducting material coupled through a normal metal to the first portion and a second d-wave superconducting material coupled through a second normal metal to the second portion, the portion of the phase shift being determined by the difference in crystallographic directions in a grain boundary interface between the first d-wave superconducting material and the second d-wave superconducting material.

68. The method of Claim 62, wherein forming a qubit includes forming a superconducting loop that includes a ferromagnetic junction, a portion of the phase shift being produced by the ferromagnetic junction.

69. The method of Claim 62, wherein forming the superconducting loop includes forming a first portion and a forming second portion wherein the first portion and the second portion are coupled by the ferromagnetic junction.

70. The method of Claim 62, wherein forming the qubit includes forming a superconducting loop from a d-wave superconducting material wherein a

portion of the phase shift is formed by grain boundaries in the d-wave superconducting material of the superconducting loop.

71. The method of Claim 62, wherein the phase gate operation is a σ_x operation and passing a current through the multi-terminal junction includes passing current symmetrically through the multi-terminal junction.

72. The method of Claim 62, wherein the phase gate operation is a σ_z operation and passing a current through the multi-terminal junction includes passing current asymmetrically through the multi-terminal junction.

73. The method of Claim 62, wherein the multi-terminal junction is arranged so that current can pass through the multi-terminal junction both symmetrically and asymmetrically.

74. The method of Claim 73, wherein the multi-terminal junction is a five-terminal junction.

75. The method of Claim 62, wherein the multi-terminal junction is a four-terminal junction.

76. A method of reading a state of a qubit, comprising:

providing a qubit, the qubit including a superconducting loop coupled to a multi-terminal junction, the superconducting loop providing a phase shift;

applying a current asymmetrically through the multi-terminal junction; and

determining whether a resistance has developed across the multi-terminal junction,

wherein absence of a resistance across the multi-terminal junction indicates a first state and presence of resistance across the multi-terminal junction indicates a second state.

77. The method of Claim 76, wherein providing a qubit comprises providing a multi-terminal junction that includes at least one constriction junction.

78. The method of Claim 76, wherein providing a qubit comprises providing a multi-terminal junction that includes at least one tunnel junction.

79. The method of Claim 76, wherein providing a qubit includes providing a multi-terminal junction that includes at least one two-dimensional electron gas structure.

80. The method of Claim 76, wherein providing a qubit includes providing a superconducting loop that includes a first portion of a s-wave superconducting material and a second portion of a s-wave superconducting material and wherein a portion of the phase shift is produced by a d-wave superconducting material coupled to the first portion and the second portion through normal metal interfaces, the portion of the phase shift being determined by the angle between the normal metal interface and crystallographic directions in the d-wave superconducting material.

81. The method of Claim 76, wherein providing a qubit includes providing a superconducting loop that includes a first portion of a s-wave superconducting material and a second portion of a s-wave superconducting material and wherein a portion of the phase shift is produced by a first d-wave superconducting material coupled through a normal metal to the first portion and a second d-wave superconducting material coupled through a second normal metal to the second portion, the portion of the phase shift being determined by the difference in crystallographic directions in a grain

boundary interface between the first d-wave superconducting material and the second d-wave superconducting material.

82. The method of Claim 76, wherein forming a qubit includes forming a superconducting loop that includes a ferromagnetic junction, a portion of the phase shift being produced by the ferromagnetic junction.

83. The method of Claim 76, wherein forming the superconducting loop includes forming a first portion and a forming second portion wherein the first portion and the second portion are coupled by the ferromagnetic junction.

84. The method of Claim 76, wherein forming the qubit includes forming a superconducting loop from a d-wave superconducting material wherein a portion of the phase shift is formed by grain boundaries in the d-wave superconducting material of the superconducting loop.

85. The method of Claim 76, wherein the current is greater than a lower critical current of the multi-terminal junction when the qubit is in the second state and less than a greater critical current of the multi-terminal junction when the qubit is in the first state.

86. The method of Claim 85, wherein the multi-terminal junction is a four-terminal junction.

87. The method of Claim 76, wherein the multi-terminal junction is a five terminal junction.

88. A method of entangling two qubits in a qubit array, comprising:

switchably capacitively coupling a voltage into an entanglement junction, the entanglement junction being coupled between superconducting loops of the two qubits.

89. The method of Claim 88, wherein at least one of the two qubits includes a superconducting loop coupled to a multi-terminal junction, the superconducting loop providing a phase shift.

90. The method of Claim 97, wherein the quantum states of the two qubits are entangled in the absence of the voltage.

91. A method of tuning a qubit, comprising:

providing a qubit, the qubit including a superconducting loop coupled to a multi-terminal junction, the superconducting loop providing a phase shift;

providing a current symmetrically through the multi-terminal junction, the current adjusting a tunneling frequency between quantum states on the qubit.

92. The method of Claim 91, wherein the tunneling frequency is adjusted to correspond to the tunneling frequency of other qubits in a qubit array.